Specifications for a VLB Water Vapor Radiometer

D. E. Hogg

May 10, 1983

The NRAO is considering the construction of a prototype water vapor radiometer (WVR), which ultimately could be used to correct VLB observations for the effects of water vapor. This note discusses the specifications of the system.

A. GENERAL NATURE OF THE DEVICE

I know of four WVR's that either are already in the field or are about to be deployed. The characteristics of these are given in the table. All are dual frequency devices using two channels of data in order to estimate both the water vapor and liquid water content. The most detailed work has been done by the NOAA group (Westwater, Guiraud, D. C. Hogg et al.) who have made a long series of measurements to test the accuracy of the method. I recommend that we pattern our WVR generally after theirs.

The NOAA WVR is described by Guiraud, Howard, and Hogg (1979). It consists of two receivers, one at 20.6 GHz, the other at 31.6 GHz. There is some flexibility in these frequencies. The lower one has been chosen to minimize the sensitivity of the experiment to pressure-broadening in the atmosphere, while the higher one lies in the window between the water vapor and oxygen lines.

The receivers should be fed by horns having beamwidths of a few degrees. I don't think the exact size matters when the WVR is being used by itself to monitor extinction at the VLA site, but it is important that the beamwidths be the same at the two frequencies. Ultimately the WVR will have to be matched to the feed system of the VLBA antenna, if it is to be mounted on the dish.

As will be shown later, I think that the sensitivity will be limited by receiver stability, rather than by system noise. This was certainly true for the VLA experiments done using the JPL radiometers (Resch, Hogg and Napier 1983). The triple-switched system of Guiraud et al. apparently is very stable. Other possibilities include gain modulation, noise addition, or a cryogenically-cooled reference load. These options can be explored during the design stage.

These devices are useful except when the optical depth at 31 GHz is large (Guiraud et al.; Resch et al.). It might be possible to increase the accuracy of the estimate of vapor in the presence of cloud by adding a third channel at, say, 24 GHz. The additional channel might also enable the estimate of vapor to be more accurate in the case of a disturbed atmosphere, where the assumption of a "standard" atmosphere in deriving total path length begins to break down. However, I believe that the two-channel device will give acceptable results for such a large fraction of the time that the addition of the third channel is not justified.

B. SENSITIVITY OF THE WVR

Let the brightness temperature of the sky measured at 20.6 GHz and 31.6 GHz be Tb (20) and Tb (31) K, respectively. The precipitable water, in cm, is given by V (Guiraud et al. 1979), where

$$V = -0.19 + 0.118\ Tb\ (20) - 0.056\ Tb\ (31)$$

The excess radio path length L in cm corresponding to V is (Hogg, Guiraud, and Decker 1981)

$$L = 6.5\ V$$

If the errors in Tb (20) and Tb (31) are uncorrelated and of about the same magnitude δT, the error introduced into L is

$$\delta L \sim 0.85\ \delta T$$

As a goal, we should try to measure the difference between two WVR's to an accuracy equivalent to about 20 degrees of phase at 43 GHz, or approximately 1/2 degree of phase per GHz. This implies that for an individual radiometer.

$$\delta L = 0.03\ \text{cm}$$

$$\text{and} \quad \delta T = 0.035\ \text{K}$$

It is reasonable to integrate for 5 seconds; this would allow us to track with fair accuracy phase changes of 6 degrees per GHz per minute, adequate for most of the cases I have seen with the VLA in the A array. This integration time, and a system temperature of 600 K typical of a good mixer implies bandwidths of ~250 MHz.

None of the above requirements are demanding in terms of what is now available. More troublesome, and for me more difficult to specify, is the long-term stability. In the VLA experiment with the JPL devices, Resch et al. 1983 had trouble with gain changes with periods of an hour or more that led to errors in the estimation of Tb of ~0.5 K, an order of magnitude greater than expected from the system temperature.

As a design spec, I would like to be able to measure, after appropriate gain calibration, the temperature of the sky to an accuracy of 0.04 K with integration time of 5 seconds at any time in an interval of two-three hours.

C. MEASUREMENT OF EXTINCTION

It is proposed that the radiometer also be used to measure extinction at the VLA site, both to provide corrections to VLA data at 1.3 cm and to evaluate the VLA site for possible future projects. Resch et al. (1983) give the opacity τ as

$$\tau = - \ln \left[\frac{Tm - Tb}{Tm - Tc} \right]$$

where Tm is the mean radiating temperature of the atmosphere (approximately 275 K)

Tb is the measured sky brightness

Tc is the microwave background temperature.

If we require that the error in opacity be no more than 0.003, then the error in Tb must be less than 0.8 K, a condition easily met by any radiometer which is useful for path length measurements.

D. SUMMARY AND RECOMMENDATIONS

- A two channel, two frequency Dicke-switched receiver system

- Frequencies 20.6 ± 0.2, 31.6 ± 0.2 GHz

- Antenna beamwidths the same at the two frequencies

- Sensitivity equivalent to a T_{SYS} of 600 K, bandwidth of 250 MHz in 5 seconds

- Gain calibration and stability to achieve measurement accuracy of 0.04 K during periods of up to 3 hours.

References:

Elgered, G. 1982 in Symposium No. 5: Geodetic Applications of Radio Interferometry. NOAA Technical Report NOS 95 NGS 24 pp. 192-200.

Guiraud, F. O., Howard, J., and Hogg, D. C. 1979, IEEE Trans. on Geoscience Electronics, GE-17, 129-136.

Hogg, D. C., Guiraud, F. O., and Decker, M. T. 1981, Astron. Astrophys. **95**, 304-307.

Matsakis, D. N. 1983 (private communication).

Resch, G. R. 1983 (private communication).

Resch, G. R., Hogg, D. E., and Napier, P. J. 1983, Radio Science (submitted).

EXISTING WATER VAPOR RADIOMETERS

	Guiraud *et al.* 1979		Resch 1983		Elgered 1982		Matsakis 1983	
	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid
Frequency GHz	20.6	31.6	20.7	31.4	21.0	31.4	20.6	31.65
Antenna Beam (deg)	2.4	2.2	7.0	7.0	6.0	6.0	1.3	1.2
System Temperature at Mixer Input (K)	675	875	575	630	550	550	700	700
IF Bandwidth (MHz)	250	250	100	100	500	500	200	200
REF Loads (K)	(413, 313)		(370, 315)		(313, 77)		Noise Diodes	